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U.S. ARMY INSTITUTE FOR RESEARCH
IN MANAGEMENT INFORMATION,
COMMUNICATIONS, AND COMPUTER SCIENCES
(AIRMICS)

TECHNOLOGY ASSESSMENT OF SUPERCONDUCTIVITY

(ASQBG-I-89-013)

February, 1989

AIRMICS
115 O'Keefe Building
Georgia Institute of Technology
Atlanta, GA 30332–0800

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704--188 Exp. Date: Jun 30, 1986

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS: NONE
2a SECURITY CLASSIFICATION AUTHORITY: N/A	3 DISTRIBUTION / AVAILABILITY OF REPORT: N/A
2b DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): ASQBG-C-89-013	5 MONITORING ORGANIZATION REPORT NUMBER(S): N/A
6a NAME OF PERFORMING ORGANIZATION: AIRMICS; 6b. OFFICE SYMBOL (if applicable): ASQBG - C	7a. NAME OF MONITORING ORGANIZATION: N/A
6c ADDRESS (City, State, and ZIP Code): 115 O'Keefe Bldg., Georgia Institute of Technology, Atlanta, GA 30332-0800	7b ADDRESS (City, State, and Zip Code): N/A
8a NAME OF FUNDING/SPONSORING ORGANIZATION: AIRMICS; 8b OFFICE SYMBOL (if applicable): ASQBG - C	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code): 115 O'Keefe Bldg., Georgia Institute of Technology, Atlanta, GA 30332-0800	10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62783A	DY10	00-08	

11 TITLE (Include Security Classification)

Technology Assessment of Superconductivity (UNCLASSIFIED)

12 PERSONAL AUTHOR(S)

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13a TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
	FROM ______ TO ______	1989, February, 13	9

16 SUPPLEMENTARY NOTATION

17 COSATI CODES		
FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Superconductivity, ceramic oxides, critical temperatures, High Temperature Superconductor, Low Temperature Superconductor

19 ABSTRACT (Continue on reverse if necessary and identity by block number)

An assessment of the current, near-term (1995), and long-term (2010) trends in Superconductivity is given.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: [X] UNCLASSIFIED / UNLIMITED [ ] SAME AS RPT. [ ] DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c OFFICE SYMBOL
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Superconductivity

I. Historical Review

Superconductivity is the name given to an exceptional combination of electric and magnetic properties in certain materials when such materials are cooled to extremely low temperatures. The temperature at which a superconductor loses its resistance is called its superconducting transition temperature or critical temperature. While in the superconducting state, it has been demonstrated that a current can flow forever in a superconductor without loss of any form. (Lynton, 1969).

It all began in 1911 when a Dutch scientist, Kamerlingh Onnes, discovered that the electrical resistance of mercury completely vanished when the metal was brought to a temperature of 4 degrees K. Two years later, he revealed a depressing fact that even tiny electric currents and magnetic fields canceled the zero resistance state of superconducting metals.

In spite of this discouraging finding, John Hulm of the University of Chicago discovered another class of superconductors in the early 1950. This superconducting material is made up with metallic compounds and alloys and has what chemists call an A15 crystalline structure. Soon after that, other superconducting materials such as niobium tin and niobium titanium were found to superconduct in high magnetic field strengths and with high current densities. Thereafter, thirty-five more years of tedious research had only raised the temperature of these superconducting materials to around 23 degrees K.

In January 1986, K. Alex Muller and J. George Bednorz of IBM's Zurich Research Laboratory discovered a new class of superconducting materials: ceramic oxides. With an oxide of lanthanum, barium, and copper, they achieved a record-breaking critical temperature of 35 degrees Kelvin. The 1987 Nobel Prize in Physics was awarded to them

because of their extraordinary discovery. Then in March 1987, Paul Chu of the University of Houston and Mau Kuen Wu of the University of Alabama crashed the liquid-nitrogen barrier with yttrium-barium-copper oxide which exhibits superconducting at 94 degrees K (Teresko, 1989).

In a recent report released by the IEEE Spectrum, dazzling developments in high-temperature superconducting have been made by researchers such as Allen Hermann & Z.Z. Sheng of the University of Arkansas, and S. Parkin from IBM-Alamaden. In February 1988, Hermann and Sheng produced a thallium-barium-calcium-copper oxide compound with an superconducting critical temperature of 106 degrees K. By formulating another version of the same compound in March 1988, Parkin achieved superconducting with the oxide compound at 125 degrees K. Nevertheless, the poisonous state of thallium has limited the actual applications of this superconducting compound.

One of the most dramatic reports came from Ahmet Erbil during the fall meeting of the Materials Research Society in Boston. Erbil, a physicist at the Georgia Institute of Technology, claimed that he had observed superconductivity in copper oxides of various composition at temperatures ranging up to 500 degrees K (Fisher, 1988). Again like other reports on room-temperature breakthrough, Erbil's report remains to be confirmed.

Despite the existence of many claims and reports of high-temperature or even room-temperature superconductivity, many of these results are either nonreproducible or have later proved unfounded. Indeed, many experts, like John Hulm, theorize that the critical temperature of the ceramic materials will not far exceed the 100 degrees Kelvin mark (Fisher, 1988).

However, scientific research is usually unpredictable. According to Robert Cava, a chemist at AT&T Bell Laboratories, chance will play an extraordinary role in finding the real warm-temperature superconductors, if they ever exist (Fitzgerald, 1988). Again,

history may repeat itself. Scientists could spend another seventy-five years looking for a new class of superconductors.

II. Currently Available

A. Capability

High Temperature Superconductor (HTS)

After all the exciting work since 1911, current researchers in the high temperature superconducting area are still being crippled by limitations (Ubois, 1988) such as:

(1) The incomplete knowledge of superconductivity in ceramics.

(2) The loss of the superconducting behaviors when ceramic oxides are forced to carry high current or to coexist with high magnetic fields.

(3) The brittleness property of most ceramic-oxide materials when operated at the superconducting region.

(4) The problem of large resistance of electrical contacts for superconductors.

(5) The oxygen-depletion characteristic of superconducting compound.

Despite these problems, innovative research in HTS is proliferating. Late last year, Argonne National Laboratory developed an experimental Messiner motor which utilizes the new ceramic-oxide HTS material. Refrigerated with liquid nitrogen, this Messiner motor is able to spin at 50 rpm with no load. However, Robert Poeppel, manager of the ceramics section in Argonne's materials and components technology division, predicts that it will take another ten years before practical and economical designs of any true HTS applications are developed (Fisher, 1988).

Low Temperature Superconductor (LTS)

For most LTS's, the phenomenon of superconductivity occurs near "absolute zero" (0 degrees K or -460 degrees F) and that requires the use of the coolant, liquid helium.

With a boiling point at 4 degrees K, the liquid helium refrigeration system is extremely complex and hard to retain. Nevertheless, important work is still being done with this technology. According to Industry Week, January 88, recently announced applications of low-temperature superconductivity include:

a. An experimental generator capable of producing 5 megavolt-amps (MVA) at 3600 rpm. by Westinghouse.

b. A large-scale energy storage device with a 30 megawatt-hour superconducting electromagnet being built by Ebasco Services Inc. and Bechtel National Inc.

c. A currently planned superconducting supercollider to be used as the world's most powerful particle accelerator.

d. Superconducting magnets used in medical diagnostics and research such as magnetic-resonance imaging and spectroscopy.

e. Extremely sensitive and accurate instrumentation such as superconducting quantum-interference devices and infrared sensors.

B. Price / performance / quality

Since most current applications are either in medical experiments or in precommercial exploration, actual figures cannot be obtained but are predicted to be highly expensive due to the complex cooling system. Below are some cost indices in this technological area (Teresko, 1988):

(1) The Defense Nuclear Agency awarded two Phase 1 contracts, each worth $14 million, to Ebasco Services Inc. and Bechtel National Inc. for the design of a superconducting magnetic energy storage (SMES) using niobium-based materials. In late 1989, one of these companies will win the $50 million contract for building such a model.

(2) The Department of Energy has estimated to spend between \$4.5 billion to \$6 billion in building the world's most powerful superconducting supercollider utilizing the LTS technology.

C Application to the IMA

None available due to the immaturity of the technology.

III. Near Term (1995)

A. Capability

High Temperature Superconductor (HTS)

Underlying the technological barriers mentioned above, ceramic oxides hold other processing/fabricating questions such as:

a. How to form the brittle ceramic into wire cable

b. How to keep the material in a stable superconducting state

c. How to orient the crystalline structure to maximize the current carrying capabilities

At the current rate of accelerating interest and effort, experts predict that most technological barriers as well as processing obstacles should be solved within a few years. If this is the case, it is further believed that HTS technology will eventually dominate the market because of its inexpensive cooling requirements. Some of its potential applications have been predicted in the following areas:

- Superconducting Quantum Interference Devices (sensitive magnetic flux detectors)

- Magnetic levitation (transportation such as the mag-lev train developed by Jan-

pan Railway)

- Magnetic shielding
- Infrared sensors
- Microwave devices
- Signal processing applications

Low Temperature Superconductor (LTS):

Due to the vast amount of investment, LTS superconducting systems are predicted to co-exist with the HTS systems in the near future. However, any system planning utilizing superconductivity in the mid-1990's will eventually exclude the low-temperature superconducting materials.

B. Price / performance / quality

With liquid nitrogen (boiling point at 77 degrees K) refrigeration, the running costs for most superconducting systems will be reduced by about 90 percent. Lower cost but commercially available LTS products will appear. The HTS will be likely in an experimental stage with minimal commercial deployment

C. Application to the IMA

Affordable and practical 'super-fast' computers which might require some form of refrigeration will appear.

IV. Long Term (2010)

The long term dream of researchers is to develop a room-temperature (293 degrees Kelvin) superconductor (RTS) which will totally eliminate the need for any refrigeration. In fact, Ahmet Erbil claimed that the compound has been reproduced several times in the lab and seems to be stable. If RTS does exist, it will be a special challenge to the power industry. The opportunities for this superconductor will be in power generation and power storage, as well as in power transmission.

However, during the 2010s, we perceive that commercial HTS applications will commence. LTS applications will gradually disappear and RTS's will be likely in laboratory research stages. Applications of HTS are predicted in the following areas:

- microwave cavities
- power transmission lines
- superconducting magnets
- energy storage devices
- particle accelerators
- rotating machinery
- medical imaging system
- levitated vehicles
- micro-chip technology
- data transmission lines.

B. Price/performance/quality

Price index is hard to project without knowing the real progress of HTS. Again, we predict a general increase in system performance with a constant decrease of system cost.

C. Application to the IMA

Depending on the maturity of HTS or RTS, future applications that will have impact to the IMA will be:

- Transmission medium with data rates up to 100 GHz within computing devices
- Computer applications with semi–conducting hydrids
- Josephson–type devices
- Transistor–like superconducting devices
- Flip–Flops

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